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(71) Applicant *(for all designated States except US)*: IDENTA I/S [DK/DK]; Kildevangsvej 9, Gøderup, DK–4000 Roskilde (DK).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: BYBJERG PEDERSEN, Lars [DK/DK]; Bysøstræde 7, DK–4300 Holbæk (DK). JOHANSEN, Ole [DK/DK]; Smedelundsgade 30, DK–4300 Holbæk (DK). KASTFELT, Svend–Ove [DK/DK]; Kildevangsvej 9, Gøderup, DK–4000 Roskilde (DK).

(74) Agent: CHAS. HUDE A/S; H.C. Andersens Boulevard 33, DK–1553 Copenhagen V (DK).

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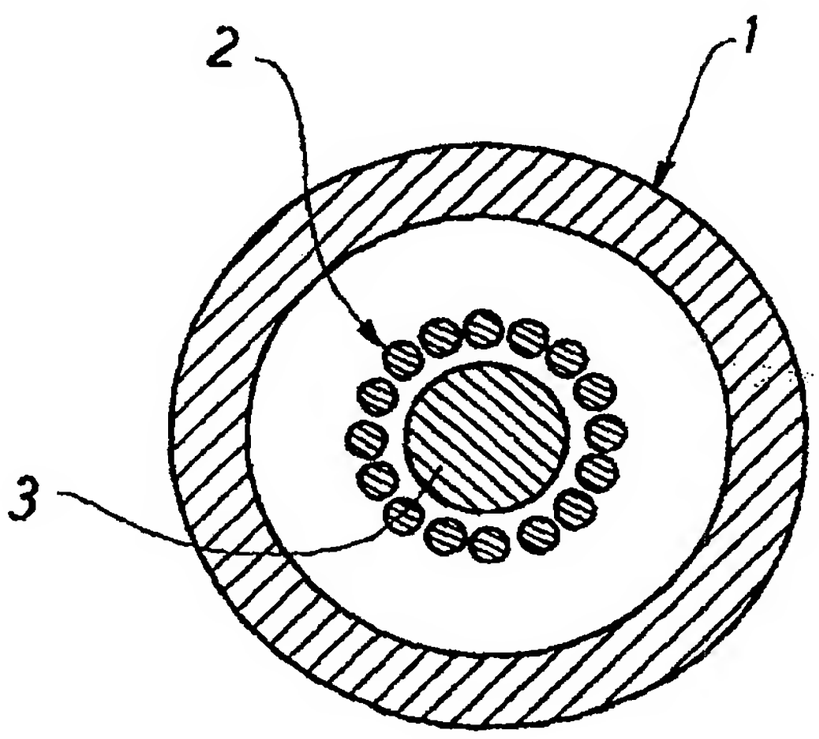
(54) Title: METHOD AND APPARATUS FOR MEASURING THE COLOUR OF A TOOTH

(57) Abstract

Method for measuring the colour of a patient's tooth, e.g. for preparing a dental prosthesis, by which method a measuring probe (1) is placed adjacent the tooth, light being emitting from the probe (1) which after reflection from the surface of the tooth is received by the same probe (1). The measuring probe (1) comprises two light conductor members (2, 3), one for transmitting light and one for receiving light, the first light conductor member (2) being formed of a bundle of light conductors concentrically arranged in relation to the second light conductor member (3). A spectroscopic member (7) communicating with a processor means (8) determines the shade of the tooth in relation to a given colour guide.



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Title: Method and apparatus for measuring the colour of a tooth.

Technical Field

The invention relates to a method for measuring the colour of a patient's tooth, eg for preparing a dental prosthesis, by which method a measuring probe is placed adjacent the tooth, light being emitted from the probe and after reflection from the surface of said tooth being received by the same probe.

Background Art

Various standard colour guides are known for use in the manufacture of dental prostheses. The material used in the manufacture of dental prostheses may be ceramic or plastic material and the manufacturers of said materials make it possible for the dental technician or the dentist to provide the patient with a dental prosthesis in a colour corresponding the patient's own teeth. Each material can be made in a number of basic colours and each basic colour can furthermore be made in a number of shades which are all variants of the primary colour. The standard colour guides from the different manufacturers of dental prosthesis material make it easier to determine which shade is to be used in each case. It is however difficult to determine the shade of a tooth merely by making a visual comparison for which reason apparatuses have been produced which can measure tooth colours according to said standard colour guides.

US patent No 4,836,674 discloses a method for measuring the colour of a tooth. By means of a light conductor light is directed to the tooth surface at the same time as the light reflected from the surface is received by means of another adjacent light conductor. However, a certain sensitivity to ambient light cannot be avoided.

Furthermore, WO 97/24075 discloses an apparatus for measuring optical characteristics of teeth by means of a plurality of adjacent light conductors, each transmitting and receiving light of a different colour. It is however necessary to submit the measured signals to signal processing in order to obtain a measurement of the shade of a tooth. Such a signal processing necessitates the use of a rather large computer. It is desirable to avoid such a computer.

Brief Description of the Invention

The object of the invention is to provide a method for measuring the colour of a tooth, said method being more simple and more effective than hitherto known.

A method of the above type is according to the invention characterised in that the measuring probe comprises two light conductor members, one for transmitting light to the tooth and one for receiving the light reflected therefrom, and that an spectrum analysis of the light received by the measuring probe is carried out to determine the colour of the tooth surface. The colour of the tooth may thus be determined by the user choosing a colour guide from among several possible guides. The tooth is then exposed to light from the measuring probe. The measuring of the light reflected from the tooth results in a number of colour intensities for different colour components of the reflected light. By means of a computer the colour which best correlates to the colour of the tooth is found. The correlation may for instance be carried out by the method of least squares, the square of the difference between the measured intensity of each colour component and the stored intensity of the same colour component being calculated, whereafter a summation of all colour components is carried out. The colour in the colour guide rendering the smallest sum, is the colour which best correlates to the colour of the tooth. As a result the requirements for signal processing are reduced compared with hitherto known processes.

If the measured colour lies between two different colours in the chosen colour guide,

the measured colour may according to the invention be presented as a mixture of the two colours. By using the same ratio mixture of the two colours in the manufacture of the prosthesis material a more accurate colour adjustment is obtained by combining the two corresponding material in said ratio. As a result a more accurate colour adjustment is obtained.

The invention also relates to an apparatus for carrying out the method according to the invention for measuring the colour of a tooth by means of a measuring probe, which can be placed adjacent the tooth. The apparatus according to the invention is characterised in that the measuring probe comprises two light conductor members, one for transmitting light to the tooth and one for receiving light reflected from the tooth, and a light source communicating with the first light conductor and a spectroscopic member communicating with the second light conductor. The resulting apparatus is particularly advantageous for carrying out the method.

Furthermore according to the invention the first light conductor member may be formed of a bundle of light conductors arranged substantially concentric in relation to the second light conductor member which optionally may be formed of a single light conductor. This arrangement is first of all space-saving, but is also advantageous in relation to measurements.

Moreover according to the invention the first light conductor member, which is concentrically arranged around the second light conductor member, may be used for transmitting light, while the second light conductor member arranged centrally in relation to the first guide member is used for receiving the light reflected from the tooth. As a result the influence of the ambient light is reduced.

Furthermore according to the invention the first light conductor member concentrically arranged around the second light conductor member may be substantially placed in form like a star. As a result the measurement is not affected by ambient light at

the same time as the light from the first light-emitting light conductor member is emitted over a large area.

Moreover according to the invention a plastic body in form of a substantially light-proof tube may be arranged in the tip of the measuring probe, the end of the body facing the probe being cut perpendicular to the longitudinal axis of the probe and the end facing away from the probe being cut at an angle of about 45° in relation to the longitudinal axis of the probe. As a result the sensitivity to ambient light is further reduced. By cutting off the body at an angle of about 45°, the insertion of the probe adjacent a surface of a tooth is further facilitated.

Furthermore according to the invention the spectroscopic member may comprise means for dispersing the light reflected from the tooth into a number of colours in the optical spectrum and an optical data collecting means such as a CCD array having a number of measuring points for recording the intensity of the different colours in the optical spectrum. Such an optical data collecting means may advantageously be formed of a CCD array, since such a CCD array is compact and provides signals corresponding to the intensity of the different colour components in a simple manner.

Finally according to the invention the optical data collecting means may communicate with a processor means which in turn communicates with a data input means and a display means. The processor means advantageously in form of a computer may thus process data from the optical data collecting means. The data input means is used for selecting the colour guide and for operating the apparatus, and the display means presents the measuring results in a manner related to the selected colour guide.

Brief Description of the Drawings

The invention is explained in greater detail below with reference to the accompanying drawings, in which

Fig. 1 shows an apparatus according to the invention for measuring the colour of a tooth and comprising a measuring probe for transmitting light and receiving the light reflected from the tooth and a member for spectrum analysis of the light reflected from the tooth,

Fig. 2 shown the measuring probe in large scale,

Fig. 3 is a sectional view along the lines I-I of the measuring probe in Fig. 2,

Fig. 4 is a longitudinal sectional view through the tip of the probe, a substantially light-proof means being arranged on said tip,

Fig. 5 shows an example of how the spectroscopic member may be formed,

Fig. 6 shows the surface of a grating forming part of the spectroscopic member,

Fig. 7 is a flow chart of an algorithm for processing the signals from the measuring probe and

Fig. 8 is a hierarchic system of colour guides with an example of how a colour of a tooth measured with the apparatus according to the invention may be classified.

Best Mode for Carrying Out the Invention

The apparatus according to the invention shown in Fig. 1 for measuring the colour of a tooth comprises a measuring probe 1 to be placed adjacent the tooth. The probe 1 has a tip housing light conductor members 2,3 for transmitting light to the tooth and for receiving the light reflected therefrom. A substantially light-proof tube 4 may be arranged on said tip. The light-proof tube 4 shields the probe tip against ambient light and may for hygienic reasons be replaced from patient to patient. A member 5

in form of a switch is provided in the probe 1 for activating the measuring state of the apparatus.

Fig. 3 is a cross-sectional view through the measuring probe in Fig. 1 alone the line I-I. The measuring probe 1 is formed of a substantially light-proof tube of for instance aluminium or stainless steel. One of the light conductor members 2 is connected to a light source, while the other light conductor member 3 is connected to a unit for spectrum analysis of the light received by the measuring probe. A configuration of the light conductor members 2,3 substantially in form of a star is compact and also advantageous in that the first light-emitting light conductor member 2 may be arranged round the second light-collecting light conductor member 3 which assists in preventing the ambient light from affecting the measurement at the same time as the light from the first light-emitting light conductor member 2 is emitted across a larger area. The light-collecting light conductor member 3 may optionally be formed of a single light conductor.

Fig. 4 is a longitudinal sectional view of the measuring probe 1 with the shielding means 4. The shielding means 4 is formed as a tube cut in one end perpendicular to its longitudinal axis and in the other end cut at an angle of about 45° relative to the longitudinal axis. The tube 4 is formed of an essentially opaque plastic material. The angle of 45° has proved substantially optimum as regards luminous yield and for preventing the second light-collecting light conductor member 3 from being exposed directly to the light from the first light-emitting light conductor member 2. As a result the second light conductor member 3 substantially only collects light reflected from the tooth.

The entire apparatus for measuring the colour of a tooth by the method according to the invention is constructed as shown in Fig. 1. In this drawing the measuring probe 1 with the built-in activation means 5 is mounted on the plastic shielding means 4 and the light conductor members 2,3, which are arranged in the probe, are each con-

nected to a light source and a spectroscopic member. Light from a light source 6 in the apparatus is then through the first light conductor member 2 transmitted to the probe 1, from where it is transmitted from the tip of the probe 1 and illuminates a tooth. The light source 6 may for instance be a halogen or a inert gas bulb of a type emitting light of a colour temperature of about 2700° K, eg of the type 1232 from the company of Welch Allyn. Light of this colour temperature is particularly suitable for this purpose, as it is easier to differentiate between the individual shades. The light reflected from the tooth is also received at the tip of the probe 1 and passed through the second light conductor member 3 to the spectroscopic member 7 in the apparatus. The spectroscopic member 7 thus renders analysis signals which are transmitted to an associated processor means 8. The processor means 8, which for instance is a computer, is further connected to a data input means 10, a display means 9 and optionally a printer 11. The spectroscopic member 7 is arranged in a housing - confer Fig. 5. The light reflected from the tooth is passed through the measuring probe 1 through the light conductor member 3 and ends in an opening of the housing. From this opening the light beam emitted by the light conductor member 3 is directed towards a concave mirror in the housing and from there towards a grating 14. The surface structure of said grating 14 is shown in a sectional view in Fig. 6 in enlarged scale and in zigzag shape, each individual plane surface being reflected or diffracted. There are about 500 grooves per mm. The principle is that the reflection grating is utilised, ie light is only transmitted in a specific direction, if diffracted light from the different facets is in phase. In other words, the phase difference of light diffracted from the different grooves or facets has to an integer of wavelengths. Light emitted in a specific direction thus has a specific wavelength as illustrated in Fig. 6. The light from this reflection grating 14 is emitted after reflection by a concave mirror with a CCD array 15, eg of the type TSL 1401 from Texas Instruments, said CCD-array 15 having 127 measuring points in form of optical detectors, each detector being sensitive to the intensity of a spectrum colour area. Such a CCD array 15 is particular suitable for supplying analysed colour data in a form suitable for processing in a computer 8. The light conductor members 2,3

in the measuring probe 1 may be in form of conventional optical fibres of suitable dimensions.

The measuring data analysed and processed by the computer 8 are displayed by means of the display means 9, and the user may by means of the data input means 10 select reference colour guides, carry out colour measurements, calibrate the measuring probe 1 and print the measuring results on the printer unit 11.

Each manufacturer's colour guide, which in this example is denoted as R, comprises a number of stored colours (denoted as r in this example) in which the dental prosthesis material may be made. The colours r are correspondingly stored for each individual colour guide in the computer 8.

The signals from the CCD array 15 are processed by means of an algorithm illustrated in Fig. 7. In the first step 101 of the algorithm the user selects a desired reference colour guide R corresponding to a set of colours in which the prosthesis material can be made and in relation to which the colour of a tooth is to be measured. In the next step 102 the spectral colour component m and a counter n are reset to zero, said component and counter serving to control to which colour component in the guide the algorithm has reached and a value-named sum is set to a 100% .In the subsequent step 103 the colour of the tooth is measured as described above and the measured values (ie the spectrally divided colour intensities) are stored as the intensities m_1, m_2 etc.. A loop is then initiated, in which the algorithm in the subsequent step 104 fetches the first of a number of stored colours in the selected colour guide R. In the following step 105 the relative difference between the intensity m_n of the measured spectral colour component and the intensity of the presently stored colour r_n of the same spectral colour component is calculated. This calculation is essentially carried out by employing the method of least squares, ie the equation $\Sigma(r_n-m_n)^2$ is minimized for all used spectral colour components. In the next step 106 the latest stored sum of $\Sigma(r_n-m_n)^2$ is compared with a calculated sum and the smallest of said two values

is stored in the following step 107. The next step 108 ensures that the calculation is repeated with the next stored value in the colour guide R in the subsequent step 109, until the measured value m_n has been compared with all of the stored values r_n in the colour guide R in question.

For each colour in the colour guide, the loop is completed in the following step 110, which checks whether all spectral colour components n (127 spectral colour components in the example) have been examined. If this is not the case, the algorithm adds one to the value n in the following step 111 and repeats the steps 104-110. When the last spectral colour component n has been examined (ie n is no longer less than 127 in the example), in the next step 112 a representation is shown on the display means 9 of the apparatus of the stored shade r closest to the measured shade m, ie the stored shade r having the most spectral colour components, whose intensities are closest to the intensities of the corresponding spectral colour components in the measured colour m. This display may be a code number, a name or another representation of the colour according to the colour guide R which is obvious for the user. The representation may also be displayed as a ratio mixture of two adjacent colours in the selected colour guide R. The concluding step 113 is used for determining whether more measurements are required in which case the algorithm is restarted. If not the algorithm is terminated. By using this algorithm the apparatus is able to find an optimum colour for a tooth in the selected colour guide in a simple and efficient manner.

Fig. 8 is a hierarchic system of colour guides with an example of how a colour of a tooth measured with the apparatus according to the invention may be classified. The prosthesis material is available in a number of basic colours, in the example denoted as colour guide R, which may be white, grey, yellow, brown etc. Each colour guide is optionally available in a number of shades from light to dark shades. If a colour m of a tooth is measured by means of the apparatus in Fig. 8 to be between the shades B3 and B4 as shown at the bottom of Fig. 8, it is possible either to select the

shade B3 (as it is closest to the measured colour) or select a combination of the shades B3 and B4 in the ratio 70% of B3 and 30% of B4 as shown in the example and thereby obtain a more accurately correlated colour in relation to the measured colour m.

The apparatus is used in the following manner: The colour guide R in relation to which the measurement is to be made is selected by means of the data input means 10. The probe 1 is mounted on a shielding tube 4 and inserted into the mouth of the patient at the tooth whose colour is to be determined. By activating the activation means 5 light is emitted through the first light-emitting light conductor member 2 towards the tooth. The light reflected from the tooth is transmitted through the second light-receiving light conductor member 3 to the spectroscopic member 7 comprising a CCD array 15 for collecting the spectrally dispersed light. The spectrally dispersed light is converted by the CCD array 15 to signals, which can be processed by the computer 8. The intensities of each of the spectral colour areas in a colour measurement jointly result in a spectroscopic shade m, which can be compared with spectrum analyses of known shades for selection of the best suitable shade.

The method and apparatus according to the invention constitute an improvement in relation to prior art in that the colour measuring is more accurate and more simple to carry out, the structure of the probe reducing the influence from ambient light and at the same time optimizes the luminous yield of the light reflected from the tooth. The interchangeable plastic tube 4 is first and foremost advantageous for hygienic reasons, but it also contributes to shielding the tip of the probe from ambient light. By means of the algorithm the computer 8 finds the optimum colour of a tooth in relation to the selected colour guide in a fast and accurate manner which does not require particular many calculation resources.

Claims

1. Method for measuring the colour of a patient's tooth, eg for preparing a dental prosthesis, by which method a measuring probe (1) is placed adjacent the tooth, light being emitting from the probe (1) which after reflection from the surface of said tooth is received by the same probe, c h a r a c t e r i s e d in that the measuring probe (1) comprises two light conductor members (2,3), one for transmitting light to the tooth and one for receiving the light reflected therefrom, and that a spectrum analysis of the light received by the measuring probe (1) is carried out to determine the colour of the surface of the tooth.

2. Method according to claim 3 c h a r a c t e r i s e d in that the a colour guide is selected from among a number of stored colour guide, the tooth in question is illuminated by means of the measuring probe (1) and the intensity of a number of colour components of the light reflected from the light is determined and the measured colour components are correlated by a processor means (8) with predetermined colour components for each colour in the colour guide, optionally by the method of least squares, in order to find the colour in the colour guide correlating the most with the colour of the tooth in question.

3. Method according to claim 2, c h a r a c t e r i s e d in that processor means (8) is adapted to present the user with a ratio mixture of two different colours in the selected colour guide, if a measured colour lies between two different colour in the selected colour guide.

4. Apparatus for carrying out the method according to one of the claims 1-3 for measuring the colour of a tooth by means of a measuring probe (1) which can be placed adjacent the tooth, c h a r a c t e r i s e d in that the measuring probe (1) comprises two light conductor members (2,3) for transmitting light toward the tooth and for receiving the light reflected from the tooth respectively, and a light source

(6) communicating with the first light conductor member (2) and a spectroscopic member (7) communicating with the second light conductor member (3).

5. Apparatus according to claim 4, c h a r a c t e r i s e d in that the first light conductor member (2) is formed of a bundle of light conductors arranged substantially concentric in relation to the second light conductor member (3) which optionally may be formed of a single light conductor.

6. Apparatus according to claim 5, c h a r a c t e r i s e d in that the first light conductor member (2), which is concentrically arranged around the second light conductor member (3), is used for transmitting light, while the second light conductor member (3) arranged centrally in relation to the first guide member is used for receiving the light reflected from the tooth.

7. Apparatus according to claim 5 or 6, c h a r a c t e r i s e d in that the first light conductor member (2) concentrically arranged around the second light conductor member (3) is substantially placed in a form like a star.

8. Apparatus according to claim one of the claims 4-7, c h a r a c t e r i s e d in that a plastic body (4) is arranged in the tip of the measuring probe (1) in form of a substantially light-proof tube, the end of the body facing the probe (1) being cut perpendicular to the longitudinal axis of the probe (1) and the end facing away from the probe (1) being cut at an angle of about 45° in relation to the longitudinal axis.

9. Apparatus according to claim one of the claims 4-8, c h a r a c t e r i s e d in that the spectroscopic member (7) comprises means (14) for dispersing the light reflected from the tooth into a number of colour components in the optical spectrum and an optical data collecting means such as a CCD array (15) having a number of measuring points for recording the intensity of the different colour components in the optical spectrum.

10. Apparatus according to one of the claims 4-9, c h a r a c t e r i s e d in that the optical data collecting means communicates with a processor means (8) which in turn communicates with an data input means (10) and a display means (9).

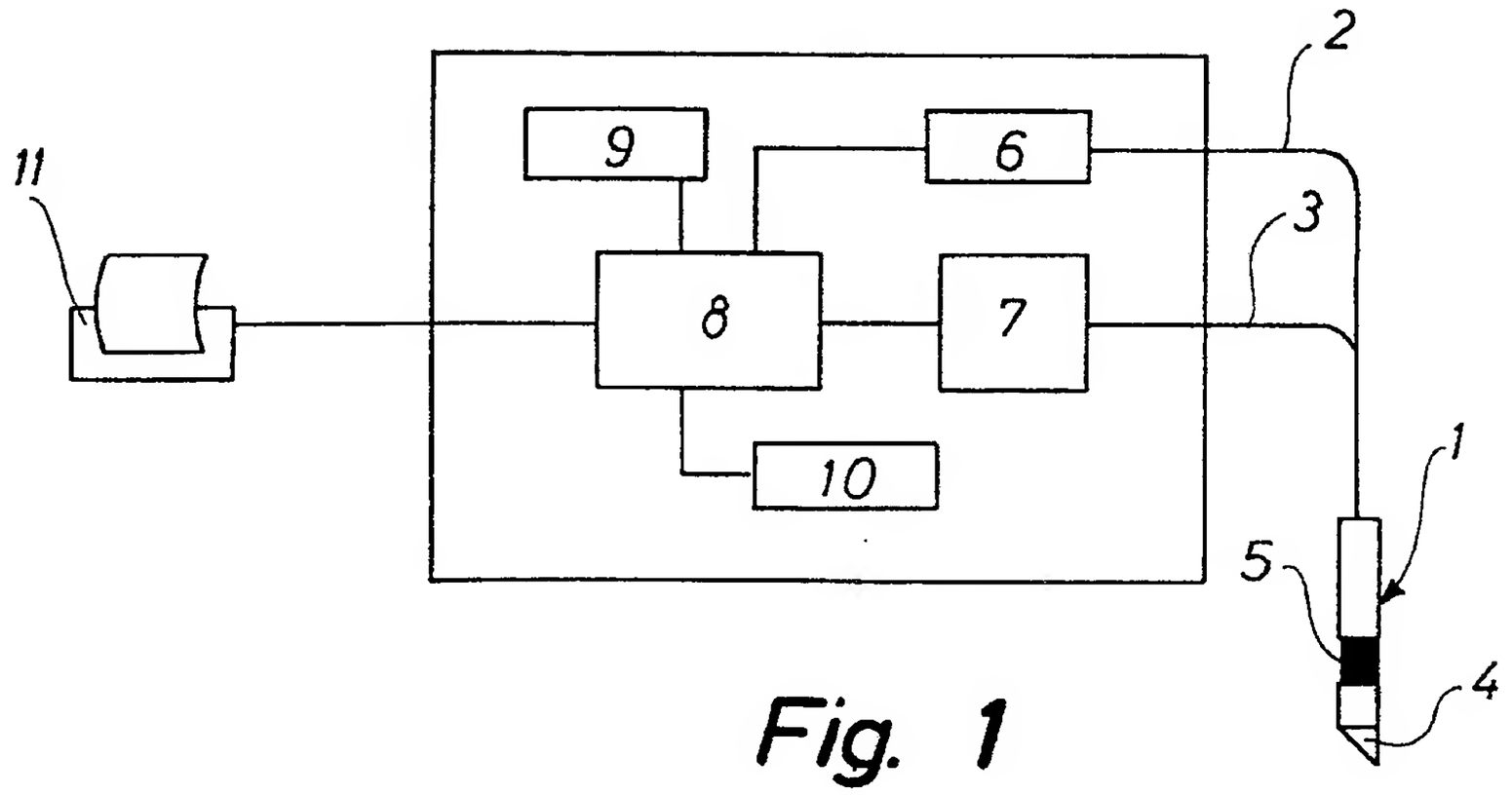


Fig. 1

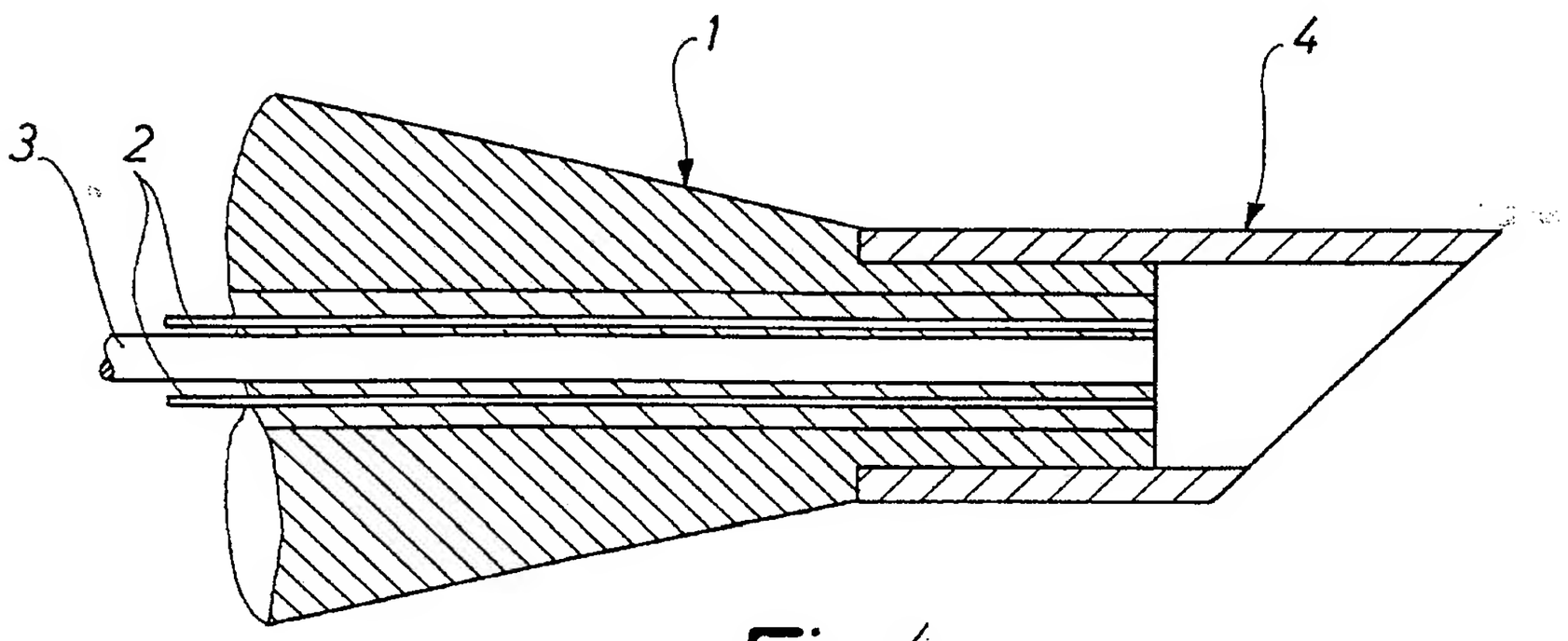


Fig. 4

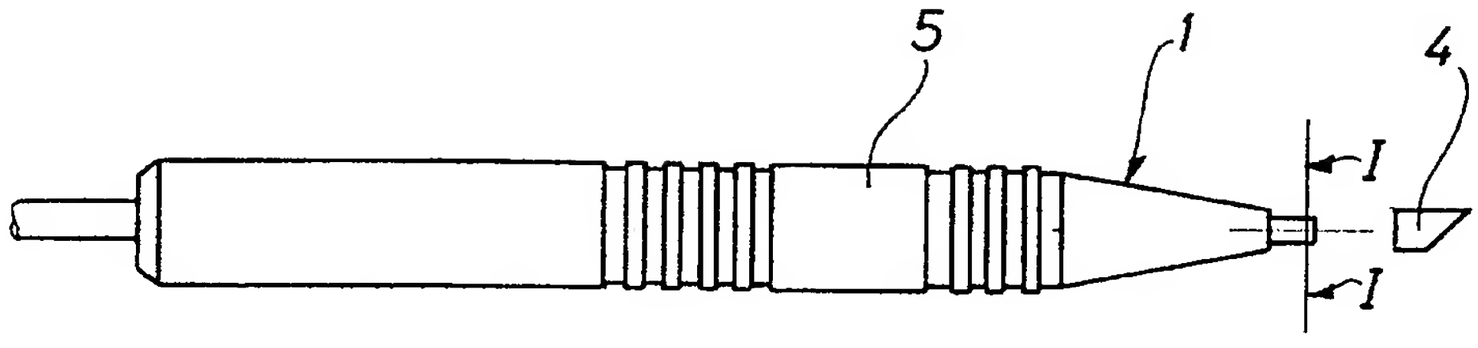


Fig. 2

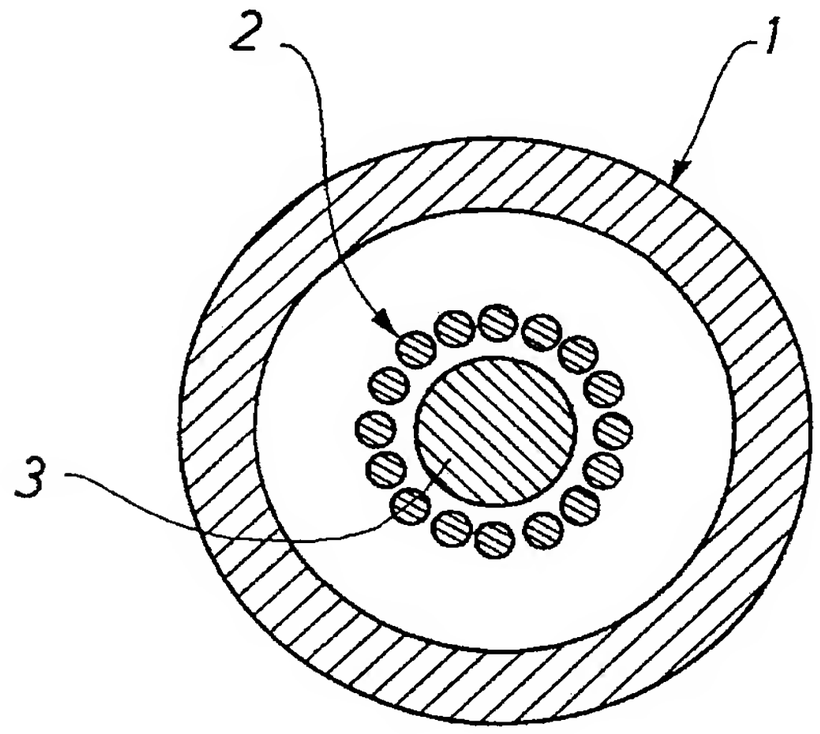


Fig. 3

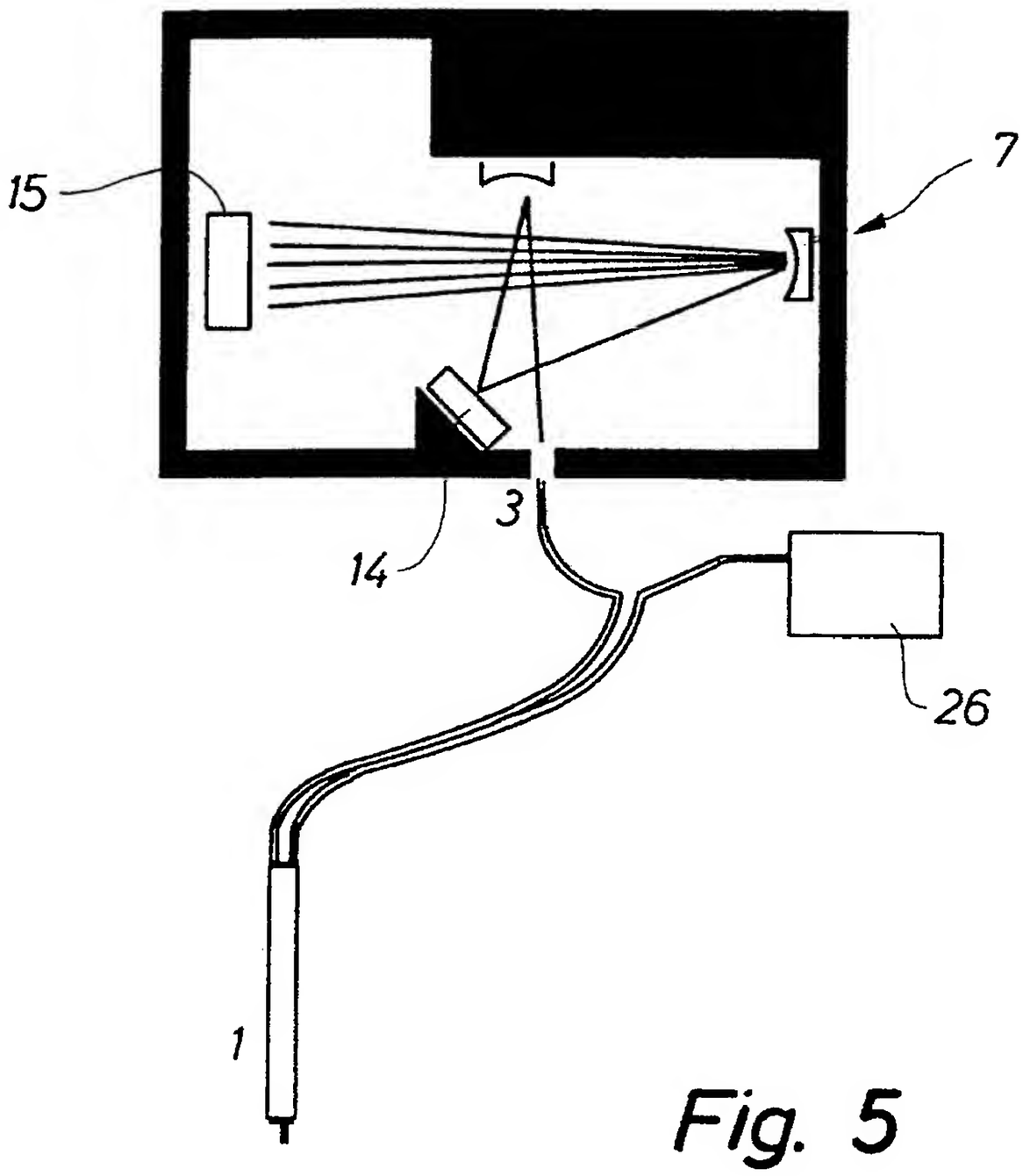


Fig. 5

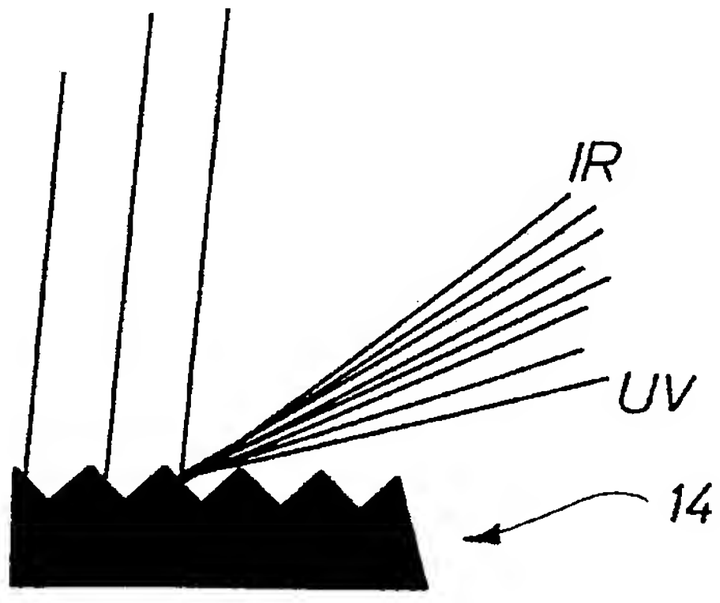
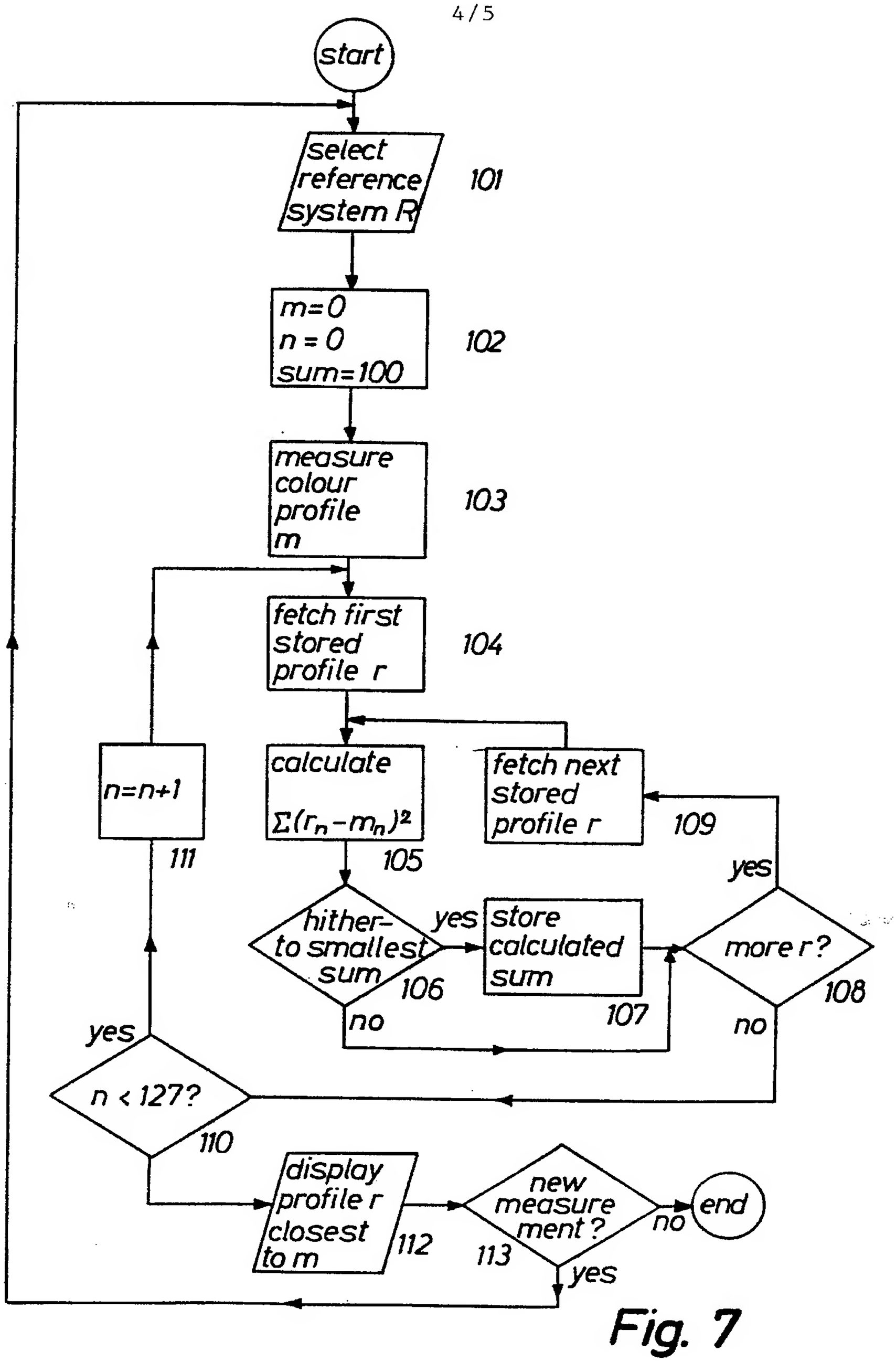


Fig. 6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select reference system R
101
m=0
n = 0
sum=100
102
measure colour profile m
103
fetch first stored profile r
104
n=n+1
111
calculate $\Sigma(r_n - m_n)^2$
105
fetch next stored profile r
109
hither-to smallest sum
106
yes
store calculated sum
107
more r?
108
yes
no
no
yes
n < 127?
110
display profile r closest to m
112
new measure ment?
113
no
end
yes

Fig. 7

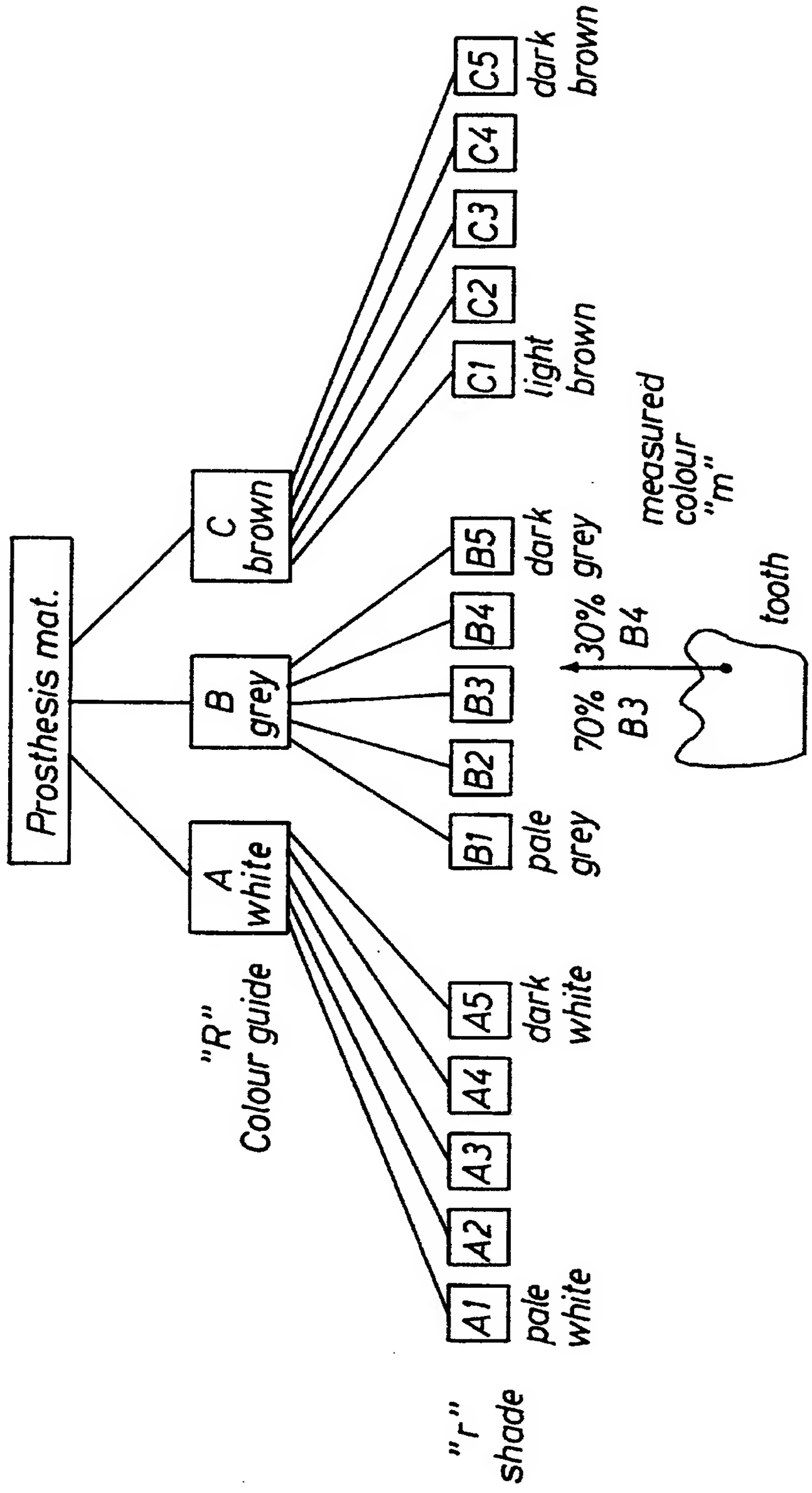
Prosthesis mat.
A white
B grey
C brown
"R" Colour guide
A1 pale white
A2
A3
A4
A5 dark white
B1 pale grey
B2
B3
B4
B5 dark grey
C1 light brown
C2
C3
C4
C5 dark brown
"r" shade
70% B3
30% B4
measured colour "m"
tooth

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 99/00459

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: A61C 19/10, G01J 3/46
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: A61C, G01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 19534517 A1 (FISCHER, HORST, DR. ET AL), 6 March 1997 (06.03.97) --	1-10
A	WO 8703470 A1 (BERTIN & CIE), 18 June 1987 (18.06.87) --	1-10
A	WO 9724075 A1 (LJ LABORATORIES, L.L.C.), 10 July 1997 (10.07.97) --	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
6 December 1999	20 January 2000 (20.01.00)
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Jack Hedlund/EÖ Telephone No. +46 8 782 25 00

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INTERNATIONAL SEARCH REPORT

Information on patent family members

02/11/99

International application No.
PCT/DK 99/00459

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